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Pacific Region
Canadian Science Advisory Secretariat
Science Advisory Report 2012/026

PACIFIC SARDINE 2011 SEASONAL BIOMASS AND MIGRATION IN BRITISH COLUMBIA AND HARVEST ADVICE FOR 2012

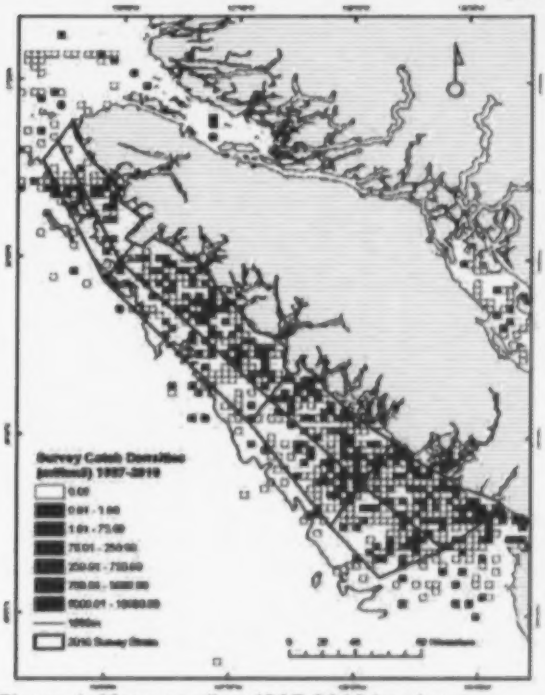

Figure 1. Mean sardine 1997-2010 trawl survey catch densities, based on 4x4km sized grid cells, and boundaries defining the core WCVI survey region.

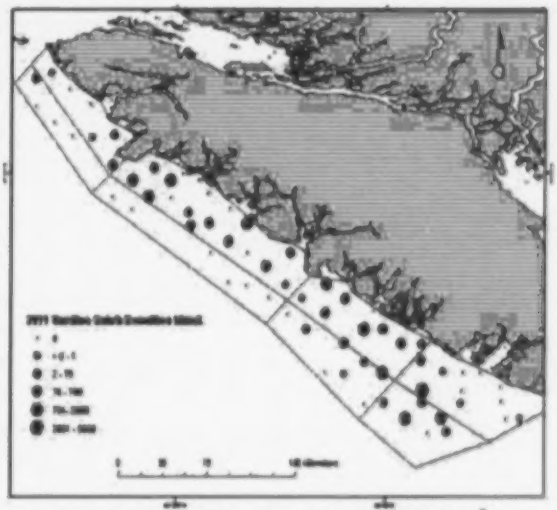

Figure 2. Sardine catch densities (tonnes/km^3) for the 2011 WCVI trawl survey, July 20-August 1.

Context :

Most Pacific sardines (Sardinops sagax) found off the west coast of the United States and Canada occur in waters off California during peak winter and spring spawning periods. In late spring, large aggregations of sardine begin to migrate northwards to summer and fall foraging areas, and then, in late fall, sardine migrate south. Foraging areas include coastal waters of British Columbia.

The sardine population collapsed to very low levels in the mid-20th century, disappearing altogether from Canadian waters. A coast-wide recovery of the stock began in the 1980s. The Canadian sardine fishery has harvested sardines experimentally since 1995 and commercially every year since they were declared not at risk by COSEWIC in 2002.

Fisheries and Oceans Canada has a Fishery Management Framework that establishes harvest control rules, sets the maximum available commercial harvest of Pacific sardine in British Columbia based on current sardine biomass estimates of the Northeast Pacific population (from a U.S. led stock assessment) and an estimated average migration rate of sardines into Canadian waters, upon which a harvest rate is established. A 15% harvest rate has been applied to the Canadian harvest control rule since 2002, which is equivalent to what has been applied to the U.S. harvest control rules.

Canada

Fisheries Management Branch requested science advice on the status of Pacific sardine summer seasonal abundance and migration, based on observations from the most recent west coast of Vancouver Island sardine survey to relate to harvest options for the 2012/2013 fishing season. This report summarizes seasonal sardine biomass and migration rate estimates into B.C. waters from the inclusion of the 2011 survey data and from updated population biomass estimates.

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat Pacific Regional Advisory Process. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

SUMMARY

- Marine waters off the west coast of Vancouver Island serve as a migratory corridor as well as preferred foraging habitat for large aggregations of Pacific sardines between June and October.
- Sardines in British Columbia waters are forage for many pelagic and migratory marine predator species.
- Population and WCVI seasonal abundance trends both show increases in sardine biomass from 2010 to 2011. The 2009 year class had above average recruitment and likely contributed to the population increase.
- In 2011, the total sardine catch from B.C. waters was 20,621 tonnes, approximately 95% of the total allowable catch of 21,917 tonnes. All harvesting occurred in waters off the WCVI, with the majority of catch coming from Pacific Fishery Management Areas 23, 25 and 123.
- Fishery Management Framework harvest control rules for setting the annual maximum available commercial harvest are based on the product of three factors: 1) current sardine biomass estimates of the Northeast Pacific population (e.g. from Ensenada Mexico to British Columbia) from a U.S. led stock assessment, 2) an estimated running average seasonal migration rate into B.C. waters, and, 3) an annual harvest rate (ranging from 5-15%) approximating what is applied in the U.S. (15% since 2002).
- Changes to the population assessment model resulted in some re-scaling of biomass estimates in the time series, which resulted in reducing 2006-2010 migration rates (and harvest rates) from previously reported estimates.
- The estimated 2011 adult (age 1 year and older) sardine biomass (and 95% confidence interval) representing the northeast Pacific California Current population as of July 2011 (from a U.S. led stock assessment) is 988,385 (619,322 – 1,357,448) tonnes.
- The estimated 2011 sardine biomass (and 95% confidence interval) for the WCVI survey region is 151,162 (82,361 – 230,051) tonnes. The extrapolated 2011 biomass estimate for mainland inshore areas is 21,822 tonnes. The extrapolated 2011 biomass estimate for WCVI inlets is 9,451 tonnes.
- The estimated three-year average sardine migration rate into B.C. waters is 18.4% and the forecasted average sardine biomass for the season starting in 2012 is 181,863 tonnes.
- Due to high levels of uncertainty associated with inshore area biomass extrapolation methods, especially in the absence of sardine observations from some inshore PFMAs, it is recommended that the methods and rules associated with estimating sardine biomass in un-surveyed areas be re-evaluated.

- Given uncertainty associated with B.C. sardine biomass forecasts under the current harvest guideline control rules, additional consideration of alternative harvest control rules and/or alternative biomass forecasting is recommended.
- Fishery Managers are advised to consider uncertainty associated with biomass forecasting for the fishing season starting in 2012 and risks of exceeding the maximum harvest rate (e.g. 15%) if there is an inter-annual decline in biomass. They are also advised to consider uncertainty associated with localized ecosystem attributes, such as incidental harvest of other species and possibly important forage habitat of sardine predators.

INTRODUCTION

Species Biology

Sardines are schooling pelagic fish found in relatively warm waters of every ocean with a global distribution restricted to 60°N and 50°S latitude. Pacific sardines (*Sardinops sagax)* in the Northeast Pacific are linked to the California Current ecosystem and the population has undergone long term fluctuations in abundance. Pacific sardines are batch spawners and spawning is thought to be restricted between 13°C to 22°C. Small females (13-15 cm) can release close to 30,000 eggs in a spawning season, whereas larger females (>20 cm) can release about 200,000 eggs in a spawning season. Sardines aged 2 to 4 generally range from 15 to 20 cm (fork length), whereas sardines aged 4 to 8 (and older) generally range from 20 to 25 cm. Year class and recruitment success can vary greatly between years, and a strong year class can comprise a significant proportion of the population for several years. The main spawning grounds for the California Current sardine population are off southern California and northwest Baja, Mexico but during warm periods, such as during strong El Niño events, environmental conditions may be conducive to sardine spawning in more northern waters, such as off the Oregon, Washington and British Columbia (B.C.) coasts; however, this does not appear to be an annual event.

Sardine movements and population structure are quite dynamic and several aspects of stock structure are poorly understood. Seasonal trends in geographic distribution and biological data (length, age, parasite and historic tagging data) show that regional connectivity in the population is complex. In general, the majority of sardines seasonally observed off B.C., Washington and Oregon are relatively large and represent older components of the population compared to sardines observed off California and Baja Mexico.

Sardines filter feed on phytoplankton and zooplankton and summer migrations into B.C. waters enable them to benefit from the marine productivity resulting from extended daylight and nutrient rich waters from oceanic upwelling and coastal run-off. Seasonal migrations are complex, with timing and extent of movements affected by population size and structure and oceanographic factors (Ware and Thompson 1991; McFarlane et al 2002). The northward migration appears to be constrained by the 12°C isotherm (Ware 2001).

Ecosystem Considerations

Sardines are a prey species for a variety of marine fishes, mammals, and seabirds. Their seasonal distribution in B.C. waters corresponds with salmon and humpback whale foraging and migrating seasons. Research continues to develop a better understanding of ecosystem processes, including environmental effects on sardine recruitment, and the role that sardines play in ecosystem structure and function.

Species of fish captured along with sardines, in commercial seine and research trawl catches include salmon, spiny dogfish, mackerel, herring and squid. Incidental capture of salmon in the commercial sardine seine fishery is monitored and area and time closures are implemented to protect sensitive salmon stocks (DFO 2011a). A bycatch framework is being considered with input from DFO fishery managers, biologists and sardine fishery representatives.

History of the Fishery

Pacific sardines have been harvested for many years, primarily by purse and drum seines, to provide a variety of products. They dominated the west coast of America fisheries during the late 1900s to 1940s, when huge quantities were reduced to fish meal and oil and some were canned. The Canadian sardine fishery began in 1917, when a small quantity was canned. Large scale reduction fishing in B.C. waters began in 1925, associated with supplying several reduction plants built along the west coast of Vancouver Island(WCVI). The B.C. fishery lasted 22 years, from 1925 to 1946, with an average annual catch of 40,000 tonnes, ranging from approximately 5 to 80,000 tonnes (Ware 1999). By the mid 1930s combined catches from Ensenada Mexico, all U.S. regions and B.C. Canada were estimated at approximately 500,000 tonnes a year. A distinct collapse in abundance was observed in B.C. waters in 1947 and then throughout the population by 1949, due to a combination of unfavourable environmental conditions and overfishing (MacCall 1979, Ware and Thomson 1991). In B.C., sardines became designated as a "Special Concern" by the *Committee on the Status of Endangered Wildlife in Canada* (COSEWIC) in 1987. The population showed some signs of recovery in U.S. waters by the 1980s and the U.S. sardine fishery reopened in 1987 when the population exceeded the minimum fishable biomass set by the state of California. By 1998, the estimated biomass of the population was 1.6 million tonnes and was declared to be fully recovered by U.S. (National Oceanic and Atmospheric Administration) fishery scientists (Hill et al. 1999). In the past decade, annual sardine catches have consistently exceeded 100,000 tonnes (Figure 3).

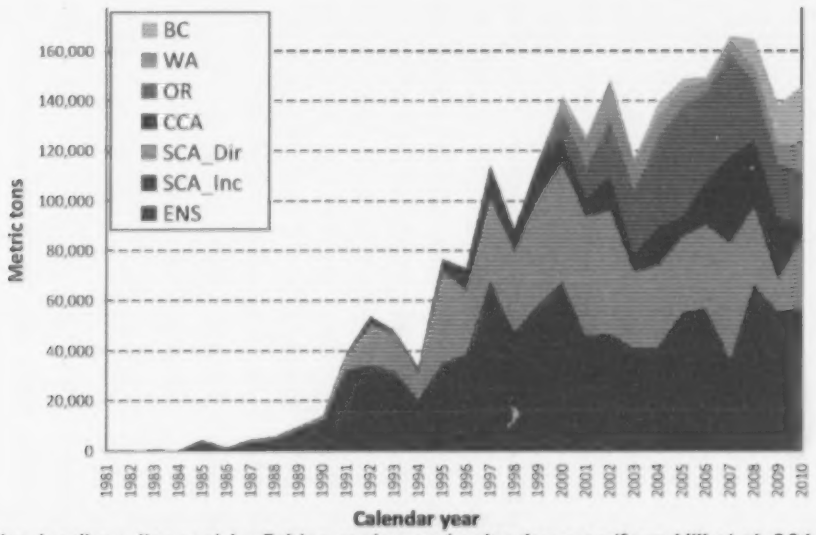

Figure 3. Sardine landings (tonnes) by fishing region and calendar year (from Hill et al. 2011 Fig. 1). Legend: BC= British Columbia; WA= Washington state; OR= Oregon state; CCA = central California; SCA_Dir and SCA_Inc = southern California directed and incidental fishing, respectively; ENS = Ensenada (Baja Mexico).

Sardines were first observed in 1992 off the WCVI and observations gradually increased in the following years. Experimental fishing off WCVI was initiated in 1995 (25 tonnes) and annual

catches increased to 1,718 tonnes in 2000 and 1,396 tonnes in 2001. Sardines were removed from the COSEWIC "Special Concern" designation in 2002, when total allowable catches (TACs) were first set using a harvest framework that utilized an estimate of the seasonal migration into B.C., the annual biomass estimate, and a harvest rate equivalent to what was applied in the U.S. (DFO 2001). In B.C., relatively small proportions of the annual TACs were realized during initial years following the re-opening of the commercial fishery in 2002, due in part to modest sardine markets at the time and competing fisheries for vessel and plant resources. Since the 1990s, products resulting from U.S. and B.C. sardine catches included bait (e.g. longline and penned tuna), frozen food (e.g. sashimi), and canned food, which are associated with markets in Australia, Asia and western Europe, but other markets have been developed. In B.C, commercial purse seine fishing has been conducted in waters along the southern central coast of B.C., the Queen Charlotte Strait and Queen Charlotte Sound, and the WCVI, represented by several Pacific Fishery Management Areas (PFMAs, Table 1 Figure 4). In recent years, the fishing season has opened June 1st and extends to February of the following calendar year; however, no or few sardine licenses have fished between December and February. Most B.C. waters have been open to commercial sardine fishing except where there are permanent fishing closures or bycatch concerns. All B.C. sardine landings since 1995 have had 100% third party dockside validation and varying proportions of the fleet are required to have at-sea observers.

Table 1. Annual sardine total allowable catch (TAC) and realized seine catch by Pacific Fishery Management Area (PFMA) for 2006-2011 (in tonnes).

Region	Year:	2006	2007	2008	2009	2010	2011
	TAC:	13,500	19,800	12,491	18,196	23,166	21,917
	PFMA	**Realized catch by year and PFMA**					
Mainland	7	0	26	0	0	0	0
	8	0	0	358	564	18	0
	9	0	25	522	3,370	1,925	0
	10	0	0	1,421	3,196	1,049	0
	12	1,558	1,181	2,462	131	320	0
	Subtotal	*1,558*	*1,232*	*4,764*	*7,262*	*3,312*	*0*
WCVI	20	0	168	0	0	0	0
	23	0	105	820	3,655	5,178	5,145
	24	0	0	301	57	1,149	677
	25	0	1	2,025	3,188	6,008	5,787
	26	0	0	1,179	249	133	1,593
	27	0	0	0	0	3,486	1,694
	121	0	0	0	0	0	77
	123	0	0	1,346	916	3,185	4,683
	124	0	0	0	0	46	703
	125	0	0	0		42	199
	126	0	0	0	0	0	62
	Subtotal	*0*	*274*	*5,671*	*8,065*	*19,227*	*20,621*
All	**All**	**1,558**	**1,507**	**10,435**	**15,327**	**22,538**	**20,621**

Figure 4. Pacific Fishery Management Areas of Fisheries and Oceans Canada.

Management Framework

The objective of the current management framework is to sustainably manage seasonal sardine aggregations in B.C. waters in a manner that conserves and protects the population at large, their habitat, and ecosystem processes, and provides fishing opportunities for First Nations, commercial and recreational harvesters (DFO 2011a). The most recent framework for generating annual maximum harvest options relevant for setting total allowable catch amounts of Pacific sardine in B.C. waters results from DFO regional advisory processes conducted in 1999, 2001, 2009 and 2011 (DFO 1999; Ware 1999; DFO 2001; Schweigert and McFarlane 2001; DFO 2009; Schweigert et al. 2009; Flostrand et al. 2011). The framework is based on the product of three factors: 1) the current population biomass estimate resulting from the annual U.S. assessment ; 2) the three-year running average seasonal migration rate (DFO 2009; DFO 2011b), determined as the ratio of sardine biomass in B.C. waters (based primarily on WCVI observations) to the population biomass, and 3) an annual harvest rate (ranging from 5-15%) approximating what is applied in the U.S. (15% since 2002, DFO 2001; Schweigert and McFarlane 2001, Hill et al 2011). No formal fishery management agreement exists between Canadian, U.S. and Mexican governing agencies.

Rationale for Assessment

Advice was requested by Fisheries Management on the status of Pacific sardine summer seasonal abundance and migration, based primarily on the most recent WCVI survey data, to develop catch options based on previously developed harvest control rules.

ASSESSMENT

Methodology and Sources of Information

The annual U.S. assessment of the population incorporates fishery catch data (landings and biological data) and research survey data (from ichthyoplankton, acoustic, trawl and aerial surveys) into an age structured model which collectively represents sardine abundance from northern Baja Mexico to B.C. Canada (Hill et al. 2011). The methods and results associated with the population assessment are formally reviewed every 2-4 years and the current version of the model is denoted as "X5". Information to characterize sardine size, age, biomass and migration in B.C. waters is based on data sets used in assessing the population and observations from a summer trawl survey off the WCVI. The WCVI trawl survey has been conducted at night since 2006 and has a core survey region with a surface area of 16,740 km^2 (Figure 1). The total volume of the WCVI core survey region is estimated at 502.2 km^3 based on the assumption that sardines primarily inhabit the upper 30m of the water column where trawl sampling occurs. Inlets are not included within the core survey region due to sampling constraints. To annually estimate sardine biomass for the WCVI core survey region, average trawl survey sardine catch densities are multiplied by 502.2 $km^3$and bootstrapping is used to estimate confidence intervals (Flostrand et al. 2011).

Provision of science advice for the 2011 fishing season included an option to incorporate estimates of sardine biomass in areas that have not been scientifically surveyed, but are near to where sardines have been commercially caught during 2006-2010, because it was recognized that the boundaries of the core survey region do not account for all areas where sardines tend to predictably aggregate on the B.C. coast. Abundance for inshore areas was estimated by extrapolating trawl survey densities to inshore PFMAs (Table 2). There is a high level of uncertainty with this approach, which the authors and formal reviewers of the 2011 research document noted (Flostrand et al. 2011; DFO 2011b). The uncertainly pertains to the spatial extent of the PFMA representation, the habitat suitability of the sub-areas and the applicability of extrapolating average trawl survey densities to these unsurveyed areas.

Stock trends and Status

Population

Recent population assessments indicate that the sardine population increased rapidly through the 1980s and 1990s, with peaks at over 1,400,000 tonnes in 2000, and 1,250,000 tonnes in 2006 (Hill et al. 2011). The population declined from 2006 to 2009 but showed some increase from 2009 to 2011(Figure 5). The most current population biomass estimate for age 1 year and older sardine, for the start of Semester 1 of the 2011 model year (starting July 1st and ending December 31st of 2011) is 988,385 tonnes. Markedly high recruitment from the 2003 year class has contributed to the population for several years and is the main reason for the 2006 peak in biomass. Low recruitment from 2006 to 2009 is thought to be the key factor for the decline in sardine biomass from 2006 to 2010, but the 2009 year class appears above average (Figure 5).

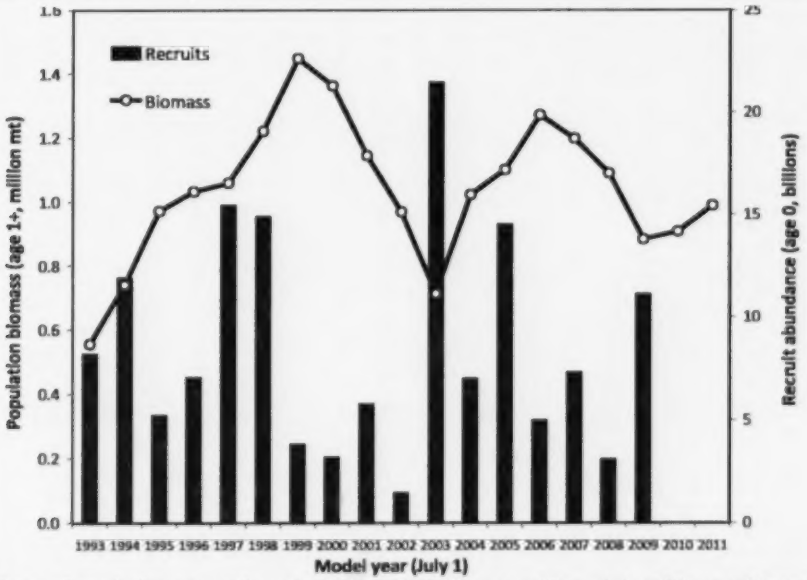

Figure 5. Abundance trends for spawning stock (age 1+) biomass (line plot, millions of tonnes) and year class strength (bar plot, billions of age-0 fish). Information from Hill et al 2011, model "X5".

British Columbia

Most sardines caught in B.C. waters are age three and older and, in recent years, relatively large proportions of the 2003 year class have been sequentially observed in British Columbia samples (Flostrand et al. 2011). Figure 6 shows age estimates from otolith samples collected from sardines during the 2011 summer trawl survey. Most sardines were aged at 5 to 8 years old and ranged in fork length from 22 to 28 cm.

Average sardine trawl survey catch densities, biomass and migration estimates decline from 2006 to 2010 but increase in 2011 (Table 2, Figure 7). During the 2011 survey, 41 of 68 trawl tows captured sardines (Figure 2). The 2011 mean trawl survey catch density (and 95% confidence interval) is 301.0 (164.0-459.9) t/km^3, which corresponds to a biomass estimate of 151,162 (82,361-230,051) tonnes. The 2009 to 2011 three-year overall average sardine catch density estimate (and 95% confidence interval) is 280.8 (147.3-442.2) t/km^3, which corresponds to an average biomass estimate of 141,034 (73,959-221,906) tonnes. The 2011 regional estimate of summer migration is 15.3% and the regional 2009 to 2011 three-year average sardine migration estimate is 15.2%.

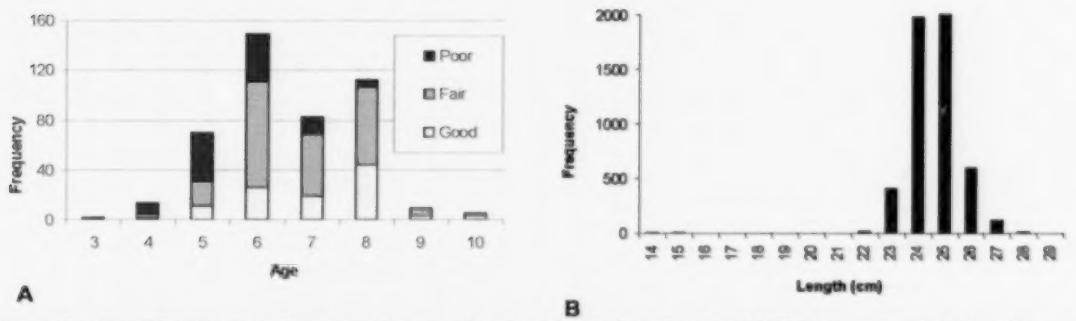

Figure 6. Results from sardine samples randomly collected during the WCVI summer 2011 trawl survey: A) Estimated age (years) by confidence ratings (poor, fair and good) from surface reading otoliths from 438 fish from 10 random samples (~ 50 fish each). Confidence ratings are a function of agreement between two readers and ranges in error reported by each reader. B) Fork lengths (cm) from 5,145 fish from 27 random samples (~200 fish each), mean of 24.2 cm and most fish 22-28 cm.

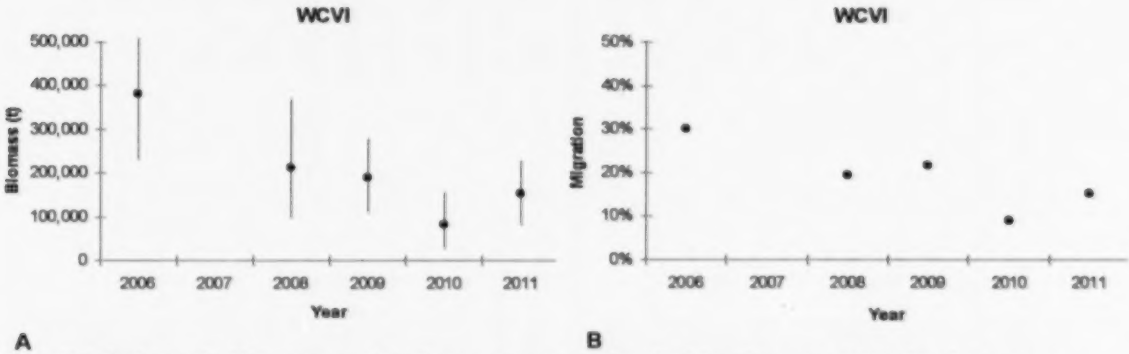

Figure 7: West coast of Vancouver Island core survey region night trawl survey estimates (no survey conducted in 2007) of: A) regional biomass (and 95% confidence intervals), and, B) migration rate (related to semester 1 population biomass).

Area and surface volume estimates of inshore PFMAs collectively increase annual WCVI core survey region biomass estimates by approximately 21% (Table 2, approximately 15% for mainland inshore and 6% for WCVI inlet extrapolation). For estimating 2011 biomass, inclusion of mainland inlets equates to an additional 21,822 tonnes and inclusion of WCVI inlets equates to an additional 9,451 tonnes. The sum of the extrapolated estimates with the 2011 biomass estimate for the WCVI core survey region is 182,435 tonnes. A 2011 biomass estimate of 182,435 tonnes corresponds with a 2011 migration rate of 18.4% and a 2009 to 2011 three-year average migration rate that is also 18.4%.

The forecast of seasonal biomass of sardine into B.C. for the fishing season beginning in 2012 is determined by the harvest control rule as the product of the 2011 summer (Semester 1) adult sardine population biomass estimate (988,385 tonnes) and the three-year average migration rate (Table 3). For an average migration rate of 15.2% (representing the WCVI core survey region only), the forecast is 150,235 tonnes. For an average migration rate of 18.4% (representing the WCVI core survey region and biomass estimated for all inshore areas), the forecast is 181,863 tonnes (Table 3).

Table 2: Estimates of sardine biomass for the WCVI core survey region, WCVI and inshore areas combined, and northeast Pacific population (northwest Baja Mexico, U.S. and Canada combined), and corresponding estimates of seasonal migration into B.C. waters for 2009-2011. LL & UL= Lower and upper 95% confidence interval limits, respectively.

Spatial representation			YEAR:	2009	2010	2011	2009-2011
	Km^2	Km^3		SARDINE DENSITY (t/km^3)			Average
WCVI survey region	16,740	502.2	Mean	378.3	163.2	301.0	280.8
			LL	220.2	57.6	164.0	147.3
			UL	557.8	309.7	459.0	442.2
				SARDINE BIOMASS (tonnes)			Average
			Mean	189,977	81,964	151,162	141,034
			LL	110,589	28,927	82,361	73,959
			UL	280,127	155,541	230,051	221,906
Mainland inshore, PFMA 7,8,9,10,12	2,418	72.5		27,427	11,832	21,822	20,360
WCVI inlets, PFMA 23-27	1,047	31.4		11,879	5,124	9,451	8,818
WCVI survey region + PFMA 7-10, 12 & 23-27	20,205	606.1		229,282	98,920	182,435	170,212
*Northeast Pacific	-	-	Mean	882,913	906,627	**988,385**	925,975
			LL	571,068	555,218	619,322	581,870
			UL	1,194,758	1,258,036	1,357,448	1,270,080
				SARDINE MIGRATION			Average
WCVI	16,740	502.2		21.5%	9.0%	15.3%	**15.2%**
WCVI + inshore areas	20,205	606.1		26.0%	10.9%	18.4%	**18.4%**

*Northeast adult sardine population (age 1 year and older) biomass confidence intervals proportional to uncertainty estimates of model year 2010 semester 2 spawning stock biomass (Hill et al. 2011)

Harvest Options

Applying Management Framework harvest control rules, which consist of the product of: 1) the current population biomass estimate (988,385 tonnes); 2) the three-year average seasonal B.C. migration rate estimate (15.2% or 18.4%), and 3) an annual maximum harvest rate of 15% (matching the U.S. 2012 harvest guidelines), the recommended maximum harvest options are 22,535 or 27,279 tonnes (Table 3).

Table 3. Sardine harvest control rule parameters and resulting maximum harvest options for the 2012 season for each of the three-year average B.C migration rate estimates.

Northeast Pacific sardine population biomass estimate: age 1 year and older (for July 2011)	988,385 tonnes	
B.C. regions	WCVI trawl survey region	WCVI trawl survey region + WCVI and mainland inshore areas
Migration rate estimate (2009-2011 average)	15.2%	18.4%
2012 biomass forecast (tonnes)	150,235	181,863
*Maximum harvest rate (for 2012)	15%	15%
Maximum harvest option (tonnes)	22,535	27,279

*Based on harvest framework which matches U.S. harvest rate (ranging from 5-15%).

Sources of Uncertainty

Within B.C., the main assumptions behind sardine biomass estimates relate to: 1) the timing of the trawl survey and its ability to represent a seasonal average (typically over a 4-5 month period), 2) survey vessel and trawl gear effects on sardine catchability, 3) whether average sardine densities are representative throughout the region for an average depth of 30m, and 4) whether survey densities and spatial estimates are representative of sardine occurrence in inshore areas outside the survey region.

A substantial portion of all commercially caught sardines in B.C. (since 1995) have been from PFMAs where biomass estimates have been extrapolated; however, assumptions associated with extrapolating average WCVI survey densities and spatial extents of the inshore areas have not been tested and confidence intervals cannot be assigned to extrapolated estimates. Furthermore, our understanding of sardine distribution and abundance is confounded by in-season movements. In 2011, no sardines were caught in any of the mainland PFMAs (Table 1), possibly due to a preference by the fishing fleet to fish off the WCVI. However, mid-summer sea surface temperatures were relatively cool in the Queen Charlotte Strait, Queen Charlotte Sound, Johnstone Strait and into the central coast (e.g. PFMAs 7-10 and 12), suggesting unfavourable conditions for sardine in those waters.

There are uncertainties with population biomass estimates from the U.S. assessments which incorporate acoustic, trawl, egg deposition and aerial survey methods and estimates. There is considerable uncertainty associated with representation of catch and age data used in the population assessment, in part because of particularly high error associated with determining sardine ages for older fish ($\geq$ 4 years).

In B.C., the product of the current population biomass estimate (representing age 1+ sardines in July 1 of 2011) and an updated 2009-2011 running average migration rate generates a forecast of seasonal abundance for the season beginning in 2012 for use in the Management Framework's harvest control rule. Management Frameworks in both the U.S. and Canada apply harvest control rules that set harvest options based on estimated biomass for July of the previous season, therefore if abundance decreases between seasons there would be a combined effect of both countries over-forecasting. Contributions from recruiting year-classes are poorly understood until sardines are approximately two years old, which weakens forecasting strength.

There has been some debate over possible detrimental effects to the sardine population's productivity and age-structure from each country (the U.S., Mexico and Canada) independently setting harvest allowances. Concerns include the possibility that the collective harvest rate of the three countries may exceed harvest rates applied in individual countries. Other concerns include unknown effects on stock structure and reproductive capacity from targeting younger components of the population (e.g. from southern California) versus older and larger components of the population (e.g. from B.C.).

There is also uncertainty associated with possible ecological effects from the incidental capture of other species (e.g. salmon), and removal of sardine from important foraging habitat of sardine predators (e.g. humpback whales). Work is currently being undertaken collaboratively with DFO, the fishing industry and academia to gain a better understanding of this uncertainty.

CONCLUSIONS AND ADVICE

- Population and WCVI seasonal abundance trends both show increases in sardine biomass from 2010 to 2011 (Figures 5 and 7). The 2009 year class had above average recruitment and likely contributed to the population increase.
- In 2011, the total sardine catch from B.C. waters was 20,621 tonnes, approximately 95% of the total allowable catch of 21,917 tonnes. All harvesting occurred in waters off the WCVI, with the majority of catch coming from Pacific Fishery Management Areas 23, 25 and 123.
- Changes to the U.S. population assessment model resulted in some re-scaling of biomass estimates in the time series, which resulted in reducing 2006-2010 migration rates (and harvest rates) from previously reported estimates (Flostrand et al. 2011, Hill et al. 2010).
- The estimated 2011 adult (age 1 year and older) sardine biomass (and 95% confidence interval) representing the northeast Pacific California Current population as of July 2011 (from a U.S. led stock assessment) is 988,385 (619,322 – 1,357,448) tonnes.
- B.C. sardine biomass and migration rate estimates for 2009 to 2011 are provided in Table 2 and seasonal biomass forecasts and 2012 harvest guideline results (maximum harvest recommendations) for 2012 are provided in Table 3.
- The estimated 2011 sardine biomass (and 95% confidence interval) for the WCVI survey region is 151,162 (82,361 – 230,051) tonnes. The extrapolated 2011 biomass estimate for mainland inshore areas is 21,822 tonnes. The extrapolated 2011 biomass estimate for WCVI inlets is 9,451 tonnes.
- The estimated three-year average migration rate of sardine into B.C. waters is 18.4% and the forecasted average sardine biomass for the season starting in 2012 is 181,863 tonnes.
- Due to high levels of uncertainty associated with inshore area biomass extrapolation methods, especially in the absence of sardine observations from some inshore PFMAs, it is recommended that the methods and rules associated with estimating sardine biomass in un-surveyed areas be re-evaluated.
- Given uncertainty associated with B.C. sardine biomass forecasts under the current harvest guideline control rules, additional consideration of alternative harvest control rules and/or alternative biomass forecasting is recommended.
- Fishery Managers are advised to consider uncertainty associated with biomass forecasting for the fishing season starting in 2012 and risks of exceeding the maximum harvest rate (e.g. 15%) if there is an inter-annual decline in biomass. They are also advised to consider

uncertainty associated with localized ecosystem attributes, such as incidental harvest of other species and possibly important forage habitat of sardine predators.

OTHER CONSIDERATIONS

A formal review of the WCVI survey data is planned for mid 2012 for possible future inclusion in the sardine population assessment. The U.S. has planned two coastwide surveys (Baja Mexico to B.C. Canada) in 2012 in April and July and the 2012 WCVI summer trawl survey will be co-ordinated with those efforts.

SOURCES OF INFORMATION

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat Pacific Regional Advisory Meeting of January 10, 2012 on Pacific sardine 2011 seasonal abundance and migration in British Columbia and harvest advice for 2012. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

DFO 1999. Report of the PSARC Pelagic Subcommittee Meeting November 16, 1999. DFO Can. Sci. Advis. Sec. Proceed. Ser. 1999/031. http://www.dfo-mpo.gc.ca/csas/Csas/Proceedings/1999/p99_31.pdf

DFO 2001. Report of the PSARC Pelagic Subcommittee Meeting, November 19-20, 2011. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2001/031. http://www.dfo-mpo.gc.ca/csas/Csas/proceedings/2001/PRO2001_031e.pdf

DFO 2009. Proceedings of the Pacific Scientific Advice Review Committee (PSARC) meeting for the assessment of scientific information to estimate Pacific sardine seasonal migration into Canadian waters. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2009/034. http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/Pro-CR/2009/2009_034_e.pdf

DFO 2011a. Pacific Region Integrated Fisheries Management Plan for Pacific Sardine (June 1, 2011 to February 9,2012).

DFO 2011b. Proceedings of the Centre of Science Advice, Pacific region. Assessment of Pacific sardine in British Columbia waters, with an emphasis on seasonal abundance and migration estimates. January 18, 2011. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2011/061.

Flostrand, L., Schweigert, J., Detering, J., Boldt, J., and MacConnachie, S. 2011. Evaluation of Pacific sardine stock assessment and harvest guidelines in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/096. http://www.dfo-mpo.gc.ca/Csas-sccs/publications/resdocs-docrech/2011/2011_096-eng.pdf

Hill, K., Jacobson, L., Lo., N., Yaremko, M., and Dege, M. 1999. Stock assessment of Pacific sardine for 1998 with management recommendations for 1999. California Department Fish and Game Resource Agency Marine Region Administrative report 99-4.

Hill, K.T., N.C.H. Lo,, B. J. Macewicz , P. R. Crone and R. Felix-Uraga. 2010. Assessment of the Pacific sardine resource in 2010 for U.S. management in 2011. Pacific Fishery Management Council, Nov 2010 Briefing Book, Agenda Item I.2.b. Attachment 2. 128 p.

Hill, K., Crone., P., Lo, N., Macewicz, B., Dorval, E., McDanniel, J., and Gu, Y. 2011. Assessment of the Pacific sardine resource in 2011 for U.S. management in 2012. Pacific Fishery Management Council, Nov 2011 Briefing Book, Agenda Item I.2.b. Attachment 8.

MacCall, A.D. 1979. Population estimates for the waning years of the Pacific sardine fishery. CalCOFI Rep 20:72-82.

McFarlane, G.A., Smith, P.E., Baumgartner, T.R., and J.R. Hunter. 2002. Climate variability and Pacific sardine populations and fisheries. American Fisheries Society Symposium 32: 195-214.

Schweigert, J.F., and McFarlane, G.A. 2001. Stock assessment and recommended harvest for Pacific sardine in 2002. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/126: 13p. http://www.dfo-mpo.gc.ca/CSAS/Csas/DocREC/2001/RES2001_126e.pdf

Schweigert, J., McFarlane, G.A., and Hodes, V. 2009. Pacific sardine (*Sardinops sagax*) biomass and migration rates in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/088. 14p. http://www.dfo-mpo.gc.ca/CSAS/Csas/publications/resdocs-docrech/2009/2009_088_e.pdf

Ware, D.M. 1999. Life history of Pacific sardine and a suggested framework for determining a B.C. catch quota. DFO Can. Sci. Advis. Sec. Res. Doc. 1999/204. http://www.dfo-mpo.gc.ca/CSAS/Csas/DocREC/1999/pdf/99_204e.pdf

Ware, D.M. 2001. Forecasting the time of arrival and availability of Pacific sardine in British Columbia. Unpublished manuscript prepared for DFO and B.C. Sardine Association. 22p.

Ware, D. M., and. Thompson, R. E. 1991. Link between long-term variability in upwelling and fish production in the northeast Pacific Ocean. Can. J. Fish. Aquat. Sci. 48:2296-2306.

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